Inspiral of double black holes in gaseous nuclear disks

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Summary. We study the inspiral of double black holes orbiting inside a massive rotationally supported gaseous disk, with masses in the Laser Interferometer Space Antenna (*LISA*) window of detectability. Using high–resolution SPH simulations, we follow the black hole dynamics in the early phase when gas–dynamical friction acts on the black holes individually, and continue our simulation until the form a close binary. We find that in the early sinking the black holes loose memory of their initial orbital eccentricity if they co–rotate with the gaseous disk. As a consequence the massive black holes *form a binary with very low eccentricity*. During the inspiral, gravitational capture of gas by the black holes occurs mainly when they move on circular orbits and may ignite AGN activity: eccentric orbits imply instead high relative velocities and weak gravitational focusing.

1 Introduction

Close massive black hole (MBH) binaries are natural, powerful sources of gravitational radiation, whose emission is one of the major scientific targets of *LISA* (see, e.g., Haehnelt 1994, Jaffe & Backer 2003, Sesana et al. 2005). How can MBHs reach sub–parsec distance scales and coalesce when resulting from the collision and merger of galaxies? Recently, Kazantzidis et al. (2005) explored the effect of gaseous dissipation in mergers between gas–rich disk galaxies with central MBHs, using high resolution N–Body/SPH simulations. They found that the interplay between strong gas inflows, cooling processes, and star formation, leads naturally to the formation of a close MBH pair and of massive nuclear gaseous disks around, on a scale of ~ 100 pc, close to the numerical resolution limit (updated simulations are presented by Mayer et al. in these proceedings). On smaller scales, Escala et al. (2005) have studied the role of gas on the orbital evolution of MBH binaries as a function of disk clumpiness, MBH to gas mass ratio, and orbital inclination angle. In the same context, we studied the evolution of the eccentricity, a key parameter for assessing the role played by gravitational wave emission in the orbital decay of MBH binaries in the *LISA* mass range.

2 The simulations

We perform our simulations with MBHs embedded in a spheroidal component (bulge) modeled initially as a Plummer sphere, and in a Mestel gaseous disk. We evolve the system using the N–Body/SPH code GADGET (Springel, Yoshida & White 2001).

We show the case of two MBHs of mass $10^6\,\mathrm{M}_\odot$ and $5\times10^6\,\mathrm{M}_\odot$ orbiting in the disk plane. We allow the heavier MBH (MBH1) to reach the center before the sinking process of the light one (MBH2) takes place. MBH2 is initially moving on a prograde eccentric orbit ($e = 0.95$). Figure 1, upper panel, shows the MBH distances from the center of mass, as a function of time. We find that the sinking time of MBH2 is $\simeq 10^7$ yr, and that there is a pronounced circularization of its orbit. Lower panel shows the gas mass collected by the two MBHs during their orbital evolution. Only when the orbit of MBH2 becomes circular gathering of gas can occur. Figure 2 shows, at two selected times, the face-on projection of the gas density together with the orbit of MBH2: close to pericentre the MBH has a speed larger, in modulus, than the local gas speed so that the wake is excited behind its trail, eroding the radial component of the velocity (left panel). On the other hand, near to apocentre, the MBH tangential velocity is slower than the local rotational gas velocity, so that the wake is dragged in front of the MBH, increasing its angular momentum (right panel). The net effect is the circularization of the initially eccentric MBH orbit. New simulations with pure stellar disks present the same effect.

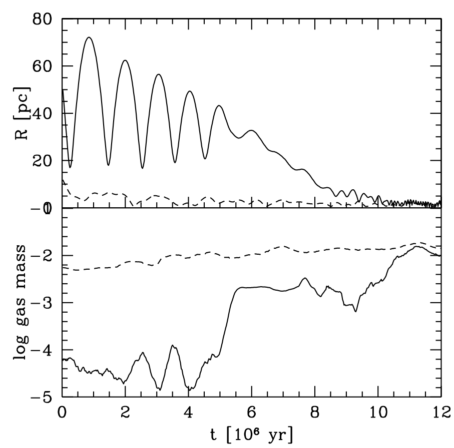

Fig. 1. Upper panel: Solid (dashed) line shows the distance R (pc) of MBH2 (MBH1) from the center of mass as a function of time. Lower panel: Solid (dashed) line shows the mass of the over-density corresponding to MBH2 (MBH1) as a function of time.

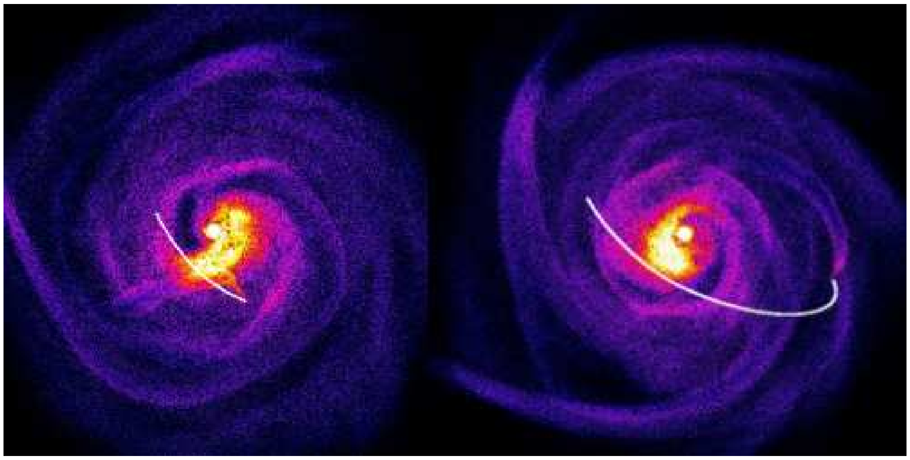

Fig. 2. Time sequence of the sinking of the MBH2. The color coding indicates the z–averaged gas density (in logarithmic scale), and the white line traces the MBH2 counterclockwise prograde orbit. In the left panel the over–density created by MBH2 is behind its current trail, while in the right panel, the BH finds its own wake in front of its path. The wake is dragged by the faster rotation of the disk.

3 Conclusion

Our main findings are:

- dynamical friction due to the MBH–gas interaction is effective down to pc distance scales
- the MBH–disk interaction circularizes prograde orbits
- substantial gas mass can be gathered along circular MBH orbits: binary coalescence could be accompanied by (double) AGN activity.

For full details and references please see: Dotti, Colpi, Haardt: MNRAS (in press, astro-ph/0509813)

References

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